Hunt. (J. S.)

THE DOMAIN OF PHYSIOLOGY;

OR

NATURE IN THOUGHT AND LANGUAGE.

BY

T. STERRY HUNT, LL.D., F.R.S.

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§ 1. The importance of a correct and well-defined terminology in science cannot be overestimated, since a want of precision in language leads to vagueness in thought, and often to errors in philosophy. There are few more striking examples of indefiniteness in language than can be found in the use of the words physic, physiology, and their derivatives. The material universe is designated with etymological correctness as physical, that is to say, natural —a term which belongs alike to the organic and the mineral kingdoms; but in the use of this and of other words having a similar etymology (Gr. φύσις, Lat. natura) we find in modern language many restrictions, limitations, and

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ambiguities. It will aid us in our present inquiry if we bear in mind that both the Greek *physis*, and the Latin *natura*, involve the notion of a generation or growth, and that the adjectives physical and natural, in their origin, imply the results of a formative process or evolution. The term *physis*, (which we translate by nature) as employed by Aristotle, denotes that which is at once self-producing, self-determined, and uniform in its mode of action.

§ 2. The substantive physic (φυσικὴ, physica, physique), has been employed by philosophers since the time of Aristotle to signify the knowledge of all material nature. "Physical science," as well defined by Clerk Maxwell at the beginning of his little treatise on *Matter and Motion*, "is that department of knowledge which relates to the order of nature, or in other words, to the regular succession of events. The name of physical science, however, is often applied, in a more or less restricted manner, to those branches of science in which the phenomena are of the simplest and most abstract kind, excluding the consideration of the more complex phenomena such as are observed in living beings."

§ 3. To the student of natural phenomena, Aristotle gave the names of *physikos* and *physiologos*. These words were adopted in the same sense by the Romans, who made use of the substantives *physicus* and *physiologia* to designate natural philosophers and natural science. Cicero writes of the physicus or physician Anaxagoras, and employs the word physiology to denote "the science of natural things" in accordance, as he tells us, with Greek usage.*

* Cicero, Varr. lib. I. R. R. cap. 40. "Si sunt semina in aere, ut ait physicus Anaxagoras;" also De Nat. Deorum, I. 4. "Rationem naturae quam physiologiam Graeci appellant." In the Totius Latinitatis Lexicon of Facciolatus and Forcellinus we find the definition; Physiologia, scientia quae de naturis rerum disserit, eadem ac Physica.

§ 4. The earlier English writers followed the Greek and Latin usage, and employed the substantive physic (or physike) in the same sense as Aristotle. Thus, in the fourteenth century, Gower defines physic as that part of philosophy which teaches the knowledge of material things, the nature and the circumstances of man, animals, plants, stones, and everything that has bodily substance.* Descartes in the seventeenth century, employed the word (in French *physique*) with the same signification, and it was subsequently used by Locke in a still more comprehensive sense. He writes of "the knowledge of things as they are in their own proper beings, their constitutions, properties and operations; whereby I mean not only matter and body, but spirits also, which have their proper natures, constitutions and operations, as well as bodies. This, in a little more enlarged sense of the word, I call φυσικὴ or natural philosophy.†

§ 5. We have seen that in Latin the words physic and physiology were used synonymously. That they were thus understood by English writers is apparent from the Universal English Dictionary of Edward Phillips, (6th edition, 1706) where Physiology is defined as "a discourse on natural things; physics or natural philosophy; being either general, that relates to the affections or properties of matter, or else special and particular, which considers matter as formed or distinguished into such and such species."

* Gower, dividing theoretical philosophy into three parts, Theologia, Physica and Mathematica, tells us: —

> "Physike is after the seconde,
> Through which the philosophre hath fonde,
> To teche sondrie knowlechynges
> Upon the bodeliches thinges
> Of man, of beast, of herb, of stone,
> Of fish, of fowl, of euerich one
> That be of bodily substance,
> The nature and the circumstance."
>
> CONFESSIO AMANTIS, book vii.

† Human Understanding, b. vii. c. 21.

Cotgrave, a lexicographer of the seventeenth century, in his "French and English Dictionary," also defines Physiologie as "a reasoning, disputing or searching-out of the nature of things," a definition which is cited by Charles Richardson in his English Dictionary, under Physiology.

§ 6. It was to those who occupied themselves with abstract or *general physiology* (as defined by Phillips,) that the Greeks gave the name of physiologists, first applied to the philosophers of the Ionian school, who sought to derive all things from one or more material elements, and thus had a physical basis for their system of the universe, as distinguished from the school of Pythagoras, whose system was based on numbers and forms. Of Empedocles, the author of a didactic poem on Nature in which we first find enunciated the doctrine of the four elements, fire, air, earth and water, Aristotle, in his Poetics, makes the criticism that he was more of a physiologist than a poet. Humboldt repeatedly employs the word physiology and its derivatives in the same general sense. Thus, he writes of "the natural philosophy of the Ionian physiologists" (physiologien), which "was devoted to the fundamental ground of origin, and the metamorphoses of one sole element"; of the "physiological fancies of the Ionian school," and of the teachings of Anaxagoras of Clazomenæ, "in the latter period of development of the Ionian physiology."* Of Anaxagoras it may be observed that his views marked a great advance over those of his predecessors, and that he merited the encomium pronounced by Aristotle that he was the first philosopher who had written soberly of nature.

§ 7. We find the word physiology and its derivatives employed in the same general sense by English writers in the seventeenth century. Thus, Cudworth speaks of "the old physiologers before Aristotle," and writes "they who first theologized did physiologize after this manner, inasmuch as they made the Ocean and Tethys to have been the

* Cosmos, Otte's translation, Harper's ed., II. 108 and III. 11.

original of generation," * while Henry Moore says, "It will necessarily follow that the Mosaical philosophy, in the physiological part of it, is the same with the Cartesian." † Coming down to later writers, we find the word physiologist used in a general sense, as equivalent to our modern term naturalist. Thus, Dugald Stewart calls Cuvier "the most eminent and original physiologist of the present age," and Burke writes, "The national menagerie is collected by the first physiologists of the time." ‡

§ 8. Of the "special and particular physiology," as distinguished by Phillips, we have an example in Glanvil, who, in the seventeenth century, writes of the physiology of comets. § The citation from Burke, identifying physiologists with zoölogists, may also perhaps be taken as an example of a special use of the word, while in later times we have come to speak of Vegetable Physiology, Animal Physiology, Human Physiology, and even of Mental Physiology, a term employed by Dr. Thomas Brown of Edinburgh, who speaks of "physiology corporeal or mental." ‖

* Intellectual System, pp. 120, 171.

† Philosophical Cabbala, Appendix c. 1.

‡ Stewart, Philosophy of the Human Mind, II. c. 4; and Burke, Letter to a Noble Lord.

§ "So that we need not be appalled at blazing stars, and a comet is no more ground for astrological presages than a flaming chimney. The unparalleled Descartes hath unravelled their dark physiology, and to wonder solved their motions." Jos. Glanvil, Scepsis Scientifica, . . . an Essay on the Vanity of Dogmatizing, 1665, c. xx.

‖ The grounds upon which Brown based this extension of the term physiology may be gathered from the following passages: "There is, in short, a science which may be called *mental physiology*, as there is a science relating to the structure and offices of our corporeal frame to which the term *physiology* is more commonly applied." He farther speaks of the "*physiology of the mind*, considered as a substance capable of the various modifications or states which, as they succeed each other, constitute the phenomena of thought and feeling," and declares that "the mind is as an object of study . . . to be comprehended, with every other existing substance, *in a system of general physics*." Brown, The Philosophy of the Human Mind, lectures I., II. and V.

[Since the writing of this essay, Prof. Osborne Reynolds, in *Nature* for June 9, 1881, (vol. xxiv, page 123) has made a happy use of the word in question, in writing of the locomotive engine of George Stephenson, of which he says, "the physiology of the machine resembled that of the human system;" while he speaks of its inventor as "he who produced the locomotive physiologically perfect."]

§ 9. There is an example of a special application of the words physiology and physic which requires farther consideration. We have already cited Cotgrave's first definition of the word Physiologie, to which he adds, as a secondary meaning, "anatomizing physic, or that part of physic which treats of the composition or structure of man's frame." In more recent times, however, the term has come to mean, not the anatomy, composition or structure of the human frame, but its functions, to which signification physiology is, in popular language, limited, though now by didactic writers extended to include the functions of the lower animals, of plants, and even of the human mind.

The word physic, as we have seen, was used by Gower in the general sense of a knowledge of all material things, but his contemporary, Chaucer, employed it, in a special and restricted sense, to designate the science of medicine. Thus, he calls his practitioner of the medical art "a doctor of physic," and in his description of this personage adds that "gold in physic is a cordial."* Subsequently, and to our own time, we find the term applied, in Chaucer's sense, alike to the

* "With us there was a doctour of phisik,
In all the world ne was there non him lyk
To speke of phisik and of surgerye,
For he was grounded in astronomye.

. . . . .

He knew the cause of every maladye,
Were it of hot or cold or moyste or drye,
And where engendered and of what humoure;
He was a very parfight practisour.

. . . . .

Well knew he the old Esculapius,
And Dioscorides, and eke Rufus,

art of healing and to its medicaments. If we search for the origin of this peculiar use of the word physic we shall find it employed with the same meaning in medieval Latin.* In French also, according to Littré, the term *physique* was in the thirteenth century applied to the science of medicine, the professors of which were then called *physiciens*, † a designation which they kept till the time of Rabelais, and, as we know, still retain in English, though the term *physicien* is at present applied in French only to students of physical science in the restricted sense mentioned in § 2, including what, in didactic phrase, is now called *physique* in French and physics in English.

§ 10. It is a curious inquiry how these terms came to have this restricted use in the middle ages, and how the name of *physicus* or physician, originally applied to the student of material things — and by pre-eminence to Anaxagoras of Clazomenae, who was called "the physician," (ὁ φυσικὸς) — came to signify in medieval France and England the *medicus*, *médecin* or mediciner — the master of the art of healing diseases in the human frame. Menage assigns as a reason for this, that the art "consists principally in the contemplation of nature," and in this imperfect statement will be found the answer to our inquiry, upon which much light is thrown by the use, in medieval times,

> Old Hippocras, Hali and Gallien,
> Serapion, Rasis and Avicen,
> Averrois, Damascene and Constantin,
> Bernard and Gatisden and Gilbertin.
>
> . . . . .
>
> For gold in phisik is a cordial.
> Therefore he loved gold in special."
>
> CHAUCER, *Canterbury Tales, Prologue.*

* Du Cange, Glossarium ad Scriptores mediae et infimae Latinitatis; ed. Henschel, sub voce Physica.

† "Nous établissons . . un fisicien juré et pensionnaire du couvent." Réglement de l'Abbaye Royale de Soissons, A. D. 1282; cited by Menage, Dictionnaire Etymologique, sub voce Physicien.

of the words *naturien* and *naturiste*. *Naturien*,* which is found in the fourteenth century, both in English and in French, is etymologically equivalent to *physicien*, and was applied to certain professors of the art of healing, being apparently synonymous with *naturiste*, which, as stated by the learned Littré, in his Dictionnaire, meant "a mediciner who practised expectant medicine, that is to say, who trusted to the conservative influences of nature to heal his patient."

§ 11. For the origin of the physician or naturian in medicine, we must go back more than twenty centuries to the great Hippocrates, justly styled the father of medicine. It was a maxim of his school that "nature is the healer of diseases," † and himself it was who wrote of medicine, that "the art consists in three things, the malady, the patient and the mediciner. The mediciner is the servant of nature, and the patient must help the mediciner to combat the disease." ‡

Nature, in the language of the time, was spoken of as a *vis medicatrix* or healing power, but Virchow justly remarks that from a careful perusal of the works left us by the great master, we cannot doubt that by nature he meant the whole bodily constitution of man. Hippocrates insisted

* The following satirical rhyme of the fourteenth century is cited by Littré, in his Dictionnaire, sub voce *Naturien*, —

> Où le physicien fait fin, Là commence le médecin.
> Supposant pour physicien, Le très-savant naturien.

Gower, who uses the word more than once, writes,—

> And thus seyth the naturien,
> Which is an astronomien.
>
> CONFESSIO AMANTIS, book vii.

† *Νούσων φύσιες ἰητροί.* Hippocrates, Epidem, book VI., sec. 5:1.

‡ Epidem, book I., sec. 2, 5. The received text makes the mediciner "the servant of the art," but Galen, in his Commentary, tells us that some manuscripts, in his time had, instead of ὁ ἰητρός υπηρέτης της τέχνης, the word φύσεος for τέχνης. This latter reading I have followed as more consonant with the previously cited dictum, for if "nature is the healer of diseases," the mediciner must be "the servant of nature." See Adams's Genuine Works of Hippocrates, vol. i., p. 360, note; also Littré's Hippocrates, vol. ii., *in loco*.

upon a treatment of diseases based not upon magic nor upon supernatural agencies, but upon the belief that nature works according to a divine necessity. In other words, he taught a system of pathology founded on the recognition of physical laws, which he opposed to the superstitious notions of his caste and his age. The *iatros*, or mediciner, was henceforth no longer a magician, nor a priest, but a physiologist, physician, or naturist, seeking for healing agencies in the study of the physical organization of the patient. The pathology of the Dogmatists, who were the disciples of Hippocrates, was based upon a knowledge of the structure and functions of the human organism, and of the structural and functional modifications produced alike by disease and by the action of drugs.

§ 12. But Hippocrates had still another claim to the title of physician, or physiologist, since, not content with studying the physical constitution of man, he insisted upon the importance of a knowledge of all his relations to external nature. In his celebrated treatise "On Airs, Waters, and Localities," Hippocrates declares that whoever would understand medicine must study the movements of the heavenly bodies, and all meteorological phenomena, together with physical geography, including climate, soil, vegetation, rocks, minerals, and waters; to which he adds that the mediciner, if he would preserve the health of his patients and succeed in his art, must investigate "everything else in nature."*

§ 13. The teachings of Hippocrates and his followers were maintained in the school of Alexandria, where, we are told, the studies were arranged in four divisions or faculties: letters, mathematics, astronomy, and medicine; under which last, as we know from the history of the Museum, were included botany, geology, chemistry, optics, and mechanics. The learning of the Alexandrian school was preserved by the Jews and the Nestorians, and by them

* Hippocrates "On Airs, Waters, and Localities;" sections 1–8.

handed down to the Arabians, who brought it with them into southern Europe. It suffices to speak of Djafar, Rhazes, Avicenna, and, later, of the schools of Salerno, Cordova, Montpellier, Narbonne, and Arles, where were gathered together men famed alike in medicine, anatomy, zoölogy, botany, optics, mechanics, and astronomy, who merited in the widest sense the name which they then bore, of physicians; since they were not simply iatro-physicians, but philosophers who had taken all natural science for their province. Draper, speaking of the Arabians of that age, says, "Their physicians were their great philosophers; their medical colleges were their foci of learning." "Arab science emerged out of medicine, and in its cultivation physicians took the lead, its beginnings being in the pursuit of alchemy."* It is to be noted that Chaucer's doctor of physic (§ 9) was not only learned in astronomy, and read in the works of the Greeks, Hippocrates, Galen, Rufus and Dioscorides, but knew well those of Ali, Avicenna, Averroes, Rhases and Damascenus, all of them renowned Arab mediciners and natural philosophers.

§ 14. The French language, as we have seen, soon came to distinguish between the physician and the professional healer of diseases. From *medicare* came the medieval Latin verb, *medicinare*, whence the French verb, *médeciner*, and the substantive *médecin*, corresponding to which we find in German and in English the substantive, *mediciner*. Sir Walter Scott puts into the mouth of King Richard the words, "It is unbecoming a mediciner of thine eminence to interfere with the practice of another,"† and Jamieson gives a Scotch proverb, "Live in measure, and laugh at the mediciners."‡ It is to be wished that this word were gen-

* Draper, Intellectual Development of Europe, I. c. 13; II. c. 4.

† The Talisman, chap. xviii.

‡ Jamieson's Scottish Dictionary has Medcinare, Medicinar and Mediciner, meaning the practitioner of medicine, thus showing a derivation from the Latin verb, *medicinare*, the second vowel being dropped in the first form.

erally adopted in our speech, since the name of physician is now given to empirics who, whatever their claims to be called curers, mediciners or medicasters, have no right to be called physicians. The antagonism between the two schools is humorously shown in the old French quatrain cited in the note to § 10.

II.

II. PHILOSOPHICAL. 15. The terms Physics and Physical. 16. Carpenter and Tyndall. 17. Thomson and Tait; Clifford; Dynamics and Dynamicist. 18. Chemism, theory of chemical changes. 19. The Chemical process defined. 20. The Unity of Force; universal Animation. 21. Organized Matter; Biotics. 22. Physiography and Physiology. 23. The Activity of Protoplasm. 24. Graham and Herbert Spencer on Colloids. 25. Barker on Vital Phenomena. 26. Biophysiology, scope of General Physiology. 27. Physiography; Huxley; Humboldt's Cosmos. 28. Physiophilosophy of Oken; Stallo. 29. Oken's system defined. 30. Physiographical and Physiological Botany. 31. Physiographical Mineralogy. 32. Structural Mineralogy and Mineral Physiology.

§ 15. Having, in the first part of this essay, considered the words physic, physiology and physician, etymologically and historically, we proceed to notice them in their application by modern writers. We have already seen that the term physical science is often restricted to those phenomena which are common to organized and unorganized matter (§ 2). The study of these is now generally designated in didactic language as physics, or in French *physique;* the votary of such studies being called in English a physicist, and in French a *physicien.*

Physical, as an adjective, is, however, used in a wider sense than the above, when applied to organized beings. It then designates their organism and all pertaining thereto, as in the expression, the physical life of man, or in the common tautological phrase, "man's physical nature."

§ 16. While the word physic, or rather physics, is in modern English generally limited to the study of the phenomena of the inorganic world, the once synonymous term physiology has come to mean, both in English and in French, the study of the organic functions of plants and animals (and, by an extension of the term, that of the functions of the human mind); which are designated as physiological, in contradistinction to the so-called physical phenomena of inorganic nature. Examples of these limitations, respectively, of the words physic and physiology, and their derivatives, are familiar to every reader. Thus, William B. Carpenter constantly distinguishes between physical, chemical and vital forces, the consideration of the latter only, according to him, belonging to physiology.*

On the other hand, we find well-known writers employing the word physical, and its congeners, indifferently, in their wider and their more restricted meanings. Thus, in his address before the British Association for the Advancement of Science, at Belfast, in 1874, Tyndall, in discussing the activities of the animal, speaks successively of "The work of the physicist. . . the comparative anatomist, and the physiologist." Following this, the influence of the nervous system "over the whole organism, physical and mental," is spoken of, and, a few lines further on, "the physical life dealt with by Mr. Darwin" is distinguished from "a psychical life"; while, in the next paragraph, we read of "organisms whose vital actions are almost as purely physical" as the coalescence of drops of oil suspended in a watery medium of the same density, in the classic experiments of Plateau.† In the first citation, the investigations by the dynamo-physicist of the nervous and muscular activities of the animal are distinguished from those of the biologist. In the second and third citations,

* Relation of the Vital to the Physical Forces, Philos. Transactions, 1850, p. 727.

† Tyndall's Belfast Address. Appleton's ed., pp. 50, 51.

the physical organism and the physical life are distinguished, not as in the preceding, from the chemical and vital (which they evidently include), but from the mental organization and the psychical life; while, in the fourth, the antithesis is between physical, in the sense of dynamical, on the one hand, and chemical and vital processes on the other.

§ 17. Thomson and Tait, in their treatise on "Natural Philosophy," wherein are considered only those simpler phenomena of matter which are neither chemical nor vital, employ the term *Dynamics* for the forces thus manifested, and divide the study of them into *Kinetics* and *Statics*, or the phenomena of actual motion and of rest. Some writers have used static as the antithesis of dynamic (see farther, § 24), but statics, as implying simply equilibrium, are, as W. K. Clifford has well remarked, "but a particular case of kinetics," and hence are to be included with the latter under the common title of dynamics. Thomson and Tait consider under this head, besides the phenomena of ordinary motion, the vibrations which produce sound, and those motions by which we seek to explain the phenomena of temperature, radiant energy, and electricity and magnetism. The whole of the phenomena to which, in the modern and restricted sense, the name of Physics is generally applied, are thereby included under the head of Dynamics; a term which is thus employed not only by the authors just cited, but by Clerk Maxwell, Helmholtz and Clifford,* and will be so used in the following pages, while the term *dynamicist* will replace physicist.

§ 18. Dynamics in the abstract regard matter in general, without relation to species, the genesis of which is the

* W. K. Clifford, Essays, II., 17. This author, following the French usage, employed the substantive Dynamic in a treatise on the subject, thus entitled; but the plural form, Dynamics, is preferable, as serving to distinguish it from dynamic used adjectively.

office of the chemical process, or chemism. This gives rise to mineralogical, or so-called chemical, species, which, theoretically, may be supposed to be formed from a single element or *materia prima*, by the chemical process.

"It is necessary to distinguish between the production of new species differing in physical characters* and that reproduction which belongs to organic existences. The distinction arises from that individuation which marks the results of organic life, and is eminently characteristic of its higher forms. The individuality, not only of the organism, but of its several parts, is more evident as we ascend the scale of organic life, while inorganic bodies have a specific existence, but no individuality; division does not destroy them. Crystallization is a commencement of individuation."

"That mode of generation which produces individuals like the parent, can present no analogy to the phenomena under consideration; metagenesis, or alternate generation, and metamorphosis are, however, to a certain extent, prefigured in the chemical changes of bodise. Their metagenesis is effected in two ways: by condensation and union, on the one hand, and by expansion and division, on the other. In the first case, two or more bodies unite and merge their specific characters in those of a new species. In the second case, this process is reversed, and a body breaks up into two or more new species. Metamorphosis is, in like manner, of two kinds: in metamorphosis by condensation only one species is concerned, and in metamorphosis by expansion the result is homogeneous and without specific difference. The chemical history of bodies is a record of these changes; it is, in fact, their genealogy."

"The processes of union and division embrace by far the greater number of chemical changes, in which metamorphosis sustains a less important part. By union, we

* That is to say: differing in dynamic relations.

rise to indefinitely higher species; but in division, a limit is met with in the production of species which seem incapable of further division, and these, being regarded as primary or original species, are called chemical elements. These two processes continually alternate with each other, and a species produced by the first may yield, by division, species unlike its parents. From this succession results double decomposition or equivalent substitution, which always involves a union followed by division, although, under the ordinary conditions, the process cannot be arrested at the intermediate stage."

§ 19. I have quoted the three preceding paragraphs from an essay published by myself in 1853, on "The Theory of Chemical Changes." Therein I also wrote, "chemical combination is interpenetration, as Kant has taught. When bodies unite, their bulks, like their specific characters, are lost in that of the new species." In 1854, in an essay entitled "Thoughts on Solution,"* I, however, declared, with regard to Kant's view, that "the conception is mechanical, and therefore fails to give an adequate idea. The definition of Hegel, that the chemical process is an identification of the different and a differentiation of the identical, is, however, completely adequate. Chemical union involves an identification not only of the volumes (interpenetration, mechanically considered), but of the specific characters of the combining bodies, which are lost in those of the new species. . . We may say that all chemical union is nothing else than solution; the

* Of the two essays above quoted, the first appeared in 1853, in the American Journal of Science for March, and also in the L. E. and D. Philos. Magazine [4], v., 526, and was translated into German in the Chemisches Centralblatt for 1853, page 849. The second was published in the American Journal of Science for January, 1854, and also in the Chemical Gazette for 1855, page 90. Both will be found in the author's volume of "Chemical and Geological Essays," in which, for the extracts here given, see pages 427, 428, and 450.

uniting species are, as it were, dissolved in each other, for solution is mutual."

The above considerations will serve to show the essential nature of chemism, a process resulting in the genesis of chemical species, which are mineral or inorganic.

§ 20. The force involved in the chemical process manifests itself as radiant energy and electricity, and there is apparently a tendency among modern dynamicists to confound these activities with chemism itself, and thus to lose sight of the essential significance of the chemical process as already defined. Thus Clifford wrote of molecular motion "which makes itself known as light, or radiant heat, or chemical action,"* while Faraday was wont "to express his conviction that the forces termed chemical affinity and electricity are one and the same." Helmholtz, from whom I here quote, adds: "I think the facts leave no doubt that the very mightiest among the chemical forces are of electrical origin, . . . but I do not suppose that other molecular forces are excluded, working directly from atom to atom." †

The activities which appear in dynamic and in chemic phenomena are one in essence, for force is one. The same is true of the activities manifested in organic growth, and even in thought; but the unity and mutual convertibility of different manifestations of force afford no ground for confounding, as some would do, dynamics with chemics, or with vital or mental processes. All of these phenomena are but the evidences of universal animation, or, in other words, of an energy which is inherent in matter, the manifestations of which, as matter rises to higher stages of development, become more complex, as organic individuals are themselves more complex than mineral forms.

* W. K. Clifford, Essays II., 17.

† Helmholtz, The Faraday Lecture, April 5, 1881; abstract prepared by its author: Nature, vol. xxiii., p. 539.

§ 21. From the process which generates chemical species we pass to that which gives rise to organized individuals, in which appear a new class of phenomena, distinguished alike from those of dynamics and those of chemism. These new manifestations, which are called vital, involve dynamical and chemical activities, but display, in addition to these, still higher ones. Matter, on this more elevated plane, not only becomes individualized, but adapts itself to external conditions, by organization, and exhibits in the resulting forms the power of growth by assimilation, and of reproduction. The study of these forms in all their relations is the object of Biology. Organogeny, or the process of morphological growth and development, distinguishes the biological from the mineralogical individual. The activities of the crystal are purely dynamic, and its crystalline individuality must be destroyed before it can become the subject even of chemism, while the plant and the animal exhibit not only dynamical and chemical, but organogenic activities, which last are designated as vital phenomena. The study of these constitutes a third division of physics which may be conveniently designated as Biotics, (from βιωτικός, pertaining to life) and have to do with organic growth, development and reproduction, activities which do not appear in the mineral kingdom.

Mineralogy is the science of inorganic matter, and studies its dynamical and chemical relations, while Biology, which is the science of organic matter, adds to these the study of biotic relations. The dynamic and chemic activities which in the mineral kingdom, give rise to the crystalline individual, are therein in static equilibrium. The organic individual, on the contrary, is kinetic, and maintains its equilibrium only by perpetual adjustment with the outer world.

§ 22. General physic, or the study of nature, presents itself under a twofold aspect, the historical and the philosophical; the former gives rise to physiography, while to the latter the name of physiology more properly belongs.

Physiography describes specific and individual forms, and their external relations, while physiology investigates the processes by which these forms are produced, and gives us the logic of nature. The physiology of matter in the abstract is dynamic, that of mineral forms is both dynamic and chemic, while that of organic forms is at once dynamic, chemic and biotic.

Nature in all its manifestations constitutes a unity, and it is the object of general physiology to study the process of creation in the material world from primal matter upward through its various forms until it attains to organization, and at length, in man, to self-consciousness, where the domain of physiology ends and that of psychology begins.

§ 23. In accordance with the views here enunciated, all matter is in a sense living, "all movement is radically vital,"* though we, in common language, refuse the designation of vital to those lower forms of material activity which appear in dynamic and chemic phenomena, reserving it for such as are supposed to be peculiar to organized forms, which, to prevent misconception, I have called biotic. When matter, through chemism, attains the condition of protoplasm, which may be chemically described as a colloidal albuminoid united with more or less water, it begins to exhibit that form of activity which we term vital, or biotic. "The mobility and the spontaneous movements of this substance," says Allman, "result from its proper irritability. From the facts there is but one legitimate conclusion, that life is a property of protoplasm." †

§ 24. Many of the peculiar characters of protoplasmic matter appear to be common to chemical species in the colloidal condition. The remarkable properties exhibited by colloids led their discoverer, Graham, twenty years

* Stallo, Philosophy of Nature, p. 66.

† Allman, Presidential Address before the British Association for the Advancement of Science, in 1879.

since, to declare, "The colloidal is, in fact, a dynamical [kinetic] state of matter, the crystalloidal being the statical condition. The colloid possesses *Energia*; it may be looked upon as the probable primary source of the force appearing in the phenomena of vitality. To the gradual manner in which colloidal changes take place (for they always require time as an element) may the characteristic protraction of chemico-organic changes also be referred." *

Following Graham, Herbert Spencer has noted that pliability, elasticity, the power of absorbing water with change of bulk, and the phenomenon of osmosis, — the whole of which are well designated by him as showing sensitiveness to external agencies which are mechanical or quasi-mechanical — are possessed in common by mineral colloids and by organized substances. These phenomena are examples of that "continuous adjustment of internal relations to external relations" which characterizes organic life.† When the chemist shall have succeeded by his synthesis in producing a colloidal albuminoid having the same chemical constitution as protoplasm, there is, as Barker has well said, reason to expect that it will exhibit all the phenomena of life which appear in the protoplasmic matter common to plants and animals.

§ 25. Barker has, in this connection, asked the important question: What are we to understand by organic life, and what is the true meaning of vital, as applied to a function? ‡ If, with him, we answer, following Küss, — "life is all that cannot be explained by dynamics and chemism," we shall find, restricting our inquiries to the animal

* Thomas Graham, Chemical and Physical Researches, p. 554, from Philosophical Transactions for 1861, p. 183.

† Herbert Spencer, Principles of Biology, vol. i., part 1, chapters 1 and 2.

‡ Geo. F. Barker, Address as President of the American Association for the Advancement of Science, Boston, August, 1880. I have in this paragraph closely followed Professor Barker's argument.

economy, that a large part of the phenomena commonly called vital, — and as such included under the head of animal physiology — are dynamic or chemic. The law of the conservation of energy applies as rigidly to a living animal as to a thermic engine, and the amount of work done, or of heat evolved, is measured by food consumed in the former as it is by the fuel burned in the latter; the energy manifested in both cases being dependent on the oxydation of carbon and hydrogen. Recent inquiries go far to confirm the view that muscular contraction is electrical, and that electrical manifestation in the muscles is, as in our ordinary batteries, dependent on chemism. The tendency of late investigations is to bring nervous activity into the same category, and the electrical nature of capillarity has been shown by Draper and by Lippmann. The animal circulation is a mechanical result of muscular contraction; the aeration and the coagulation of the blood, and the process of digestion, are chemical, while absorption finds an explanation in the phenomena of diffusion and osmosis.

When the energy which is in matter is manifested without reference to species, we call it simply dynamics; when it results in the production of mineral species, we call it chemics, or chemism; and when it gives rise to organisms, which may be defined as kinetic individuals, we distinguish it as vital, or biotic. In matter, we must recognize with Tyndall "the promise and the potency of all terrestrial life." *

§ 26. It follows, from what has been said, that the word physiology, as popularly limited to the functions of living beings, is made to include many phenomena which are not biotic, but are common to the organic and mineral kingdoms, and that we need some further definition to distinguish those which are characteristic of organic life. I therefore venture to designate the study of these

* Address as President of the British Association, Belfast, 1874. Appleton's ed., p. 59.

by the distinctive name of Biophysiology, while those phenomena which are recognized as simply dynamic, or dynamic and chemic, whether manifested in organisms or in mineral species, may be included under the name of Abiophysiology.

General physiology, comprehending these two divisions, will thus be restored to its original and proper signification, as an inquiry into the reason of all things in the material universe, and as distinguished from physiography, whose province is the description of universal nature. Scientific precision demands a reform in our terminology, and requires us to extend the name of physiology once more to the processes and the activities of the three kingdoms of nature. The inorganic, not less than the organic world, has its physiology. On the other hand, the study of mind and spirit, and the phenomena of consciousness, which Locke and Thomas Brown included under the head of physic and physiology, should be relegated to the domain of psychology.

§ 27. The kindred term physiography is now correctly employed in a general sense, with a meaning co-extensive with that which we claim for physiology. A great living teacher, Prof. Huxley, has given us, under the title of "Physiography; an Introduction to the Study of Nature," an elementary treatise, wherein, after describing the rocks, the waters, and the atmosphere, which make up the inorganic portions of the earth, he proceeds to consider their relations to each other and to the mineral kingdom, and concludes with an account of the astronomical relations of our planet as a part of the solar system.

It was the conception of the essential unity of nature, without which a true science is impossible, which inspired Humboldt to attempt, in his "Cosmos," a complete physiography, which was to be "a physical description of the universe, embracing all created things in the regions of space and in the earth." Humboldt elsewhere speaks of

"the idea of vitality . . . so intimately associated with that of the existence of the active, ever-blending natural forces which animate the terrestrial sphere," and, recalling the fact that the inorganic crust of the earth includes the same chemical elements that enter into the structure of animal and vegetable organisms, adds, "A physical cosmography would therefore be incomplete if it were to omit a consideration of these forces,—and of the substances that enter into solid and liquid combinations in organic tissues under certain conditions,—which, from our ignorance of their actual nature, we designate by the vague term of *vital forces*. The natural tendency of the human mind involuntarily prompts us to follow the physical phenomena of the earth through all their varied series, until we reach the final stage of the morphological evolution of vegetable forms, and the self-determining powers of motion in animal organisms." *

§ 28. The necessary complement to a scientific physiography is thus, as Humboldt has here pointed out, a philosophy of the material universe, or, in other words, a general physiology. The most complete attempt at thus systematizing nature is that of Lorenz Oken, who divided all philosophy into Pneumatophilosophy and Physiophilosophy, corresponding respectively to Spirit and to Nature. Physiophilosophy, as defined by him, is the science of the conversion of spirit into nature, and has for its object to show how, and in accordance with what laws, the material universe has been formed; to portray the first periods of the world's development from naught; to show how the heavenly bodies and the chemical elements originated; in what manner, by self-evolution into higher and manifold forms, these generated mineral species, became at length organic, and in man attained to self-consciousness.

* Humboldt's Cosmos, Otte's translation, Harper's ed., 1851, Author's Preface, p. viii.; and vol. i., p. 339-341.

Physiophilosophy is therefore the generative history of the world, or, in other words, the history of the process of creation. It aims, in the language of Stallo, to describe "the genetic evolution of the material world; therefore, also, its first origin in naught, and its subsequent development up to its limit, man, who is a complex of all preceding forms, includes all particular developments, and is, as it were, the focus where all the various tendencies of nature converge. . . . In man, all eternal activities, all divine ideas are gathered;" and thus it is that, in the words of the poet, he is enabled "to think again the great thought of the creation"*

§ 29. The origin of matter itself, Hylogeny, belongs to Pneumatophilosophy. The genetic process in the primal undifferentiated matter, with which Physiophilosophy first concerns itself, is by Oken considered under the two heads of Ontology and Biology. The successive steps in the ontological process are, first, Cosmogony, or the fashioning of the heavenly bodies from the previously formed matter; followed by the genesis therefrom of the chemical elements; Stoichiogeny. These elements give rise to mineral species, which together make up the earth; Geogeny. Biology, which has for its object the study of the organic world, is by Oken divided into Organogeny, with its subdivisions, and Phytosophy and Zoösophy, treating respectively of the development of plants and animals. In the organism we have "a combination of all the activities of the universe in a single individual body." The inorganic and the organic worlds are not only in harmony with each other, but are one in kind. Man, in whom self-

* "Schön ist, Mutter Natur, deiner Erfindung Pracht
Auf die Fluren verstreut; schöner ein froh Gesicht
Das den grossen Gedanken
Deiner Schöpfung noch einmal denkt."

KLOPSTOCK, *Ode; Der Zürchersee.*

Compare this with the language of Schelling, cited by Hegel; "über die Natur philosophiren heisst die Natur schaffen."

consciousness or Spirit manifests itself, represents the whole universe in miniature.*

§ 30. The physiophilosophy of Oken, of which we have given an outline, is thus identical in its aim and its plan with the earlier attempts of the Greek philosophers to which the name of physiology was given, and the two terms are, in fact, synonymous. The study of nature, as has been shown, divides itself into physiography and physiology, and this division applies equally to each one of the three great kingdoms of nature. Thus, for example, Physiographical Botany studies the relations of plants to each other as members of the vegetable kingdom, and investigates their external forms and relationships, by which we arrive at Systematic and Descriptive Botany, with its classification and terminology. These together give us Botany as a great division of Natural History. Physiological Botany, on the other hand, considers the individual plant in itself, as seen in its structure, growth and development, and in its relations to the other kingdoms of nature. It is properly divided into Structural Botany, which investigates the anatomy, organography, and morphology of the plant, and Vegetable Physiology, which studies the functions of the vegetable organism, its growth, nutrition, and decay, and the interdependence of the vegetable, animal, and mineral kingdoms.† The same distinctions and definitions

* Lorenz Oken, Physiophilosophy: Introduction, pp. 1-3, of Tulk's translation, published by the Ray Society, London, 1847. See also an excellent analysis of the system by J. B. Stallo in his Philosophy of Nature, Boston, 1848, pp. 221-330, from which we have quoted above. Errors in detail, and defects and obscurities, are to be found in the system of Oken, which even novices in science can to-day point out and criticise, but it must not be forgotten that his physiophilosophy has been a most potent influence in shaping and directing the scientific thought of the last two generations. Oken has been the inspirer and the teacher of the teachers of science.

† See Asa Gray, Structural and Systematic Botany: Introduction.

will apply, *mutatis mutandis*, to Physiographical and Physiological Zoölogy.

§ 31. The vastness and the complexity of the inorganic as compared with the organic world of nature, makes it difficult to grasp at once a conception of the true relations of Mineralogy, which comprehends the study of all forms of unorganized matter.* Physiographical Mineralogy, in its widest sense, has thus for its object not only this earth, but all other matter in space, and includes, so far as our planet is concerned, Geognosy and Petrography, besides Systematic and Descriptive Mineralogy as generally understood.

In the study of mineralogy in its physiological aspect, we have to consider the various conditions of mineral matter, distinguished as gaseous, liquid or solid, as amorphous, crystallized in different geometric forms, or colloidal. These unlike conditions of matter, and their different relations to gravity, pressure, temperature, sound, radiant energy, electricity, and magnetism, the phenomena of capillarity, and of the occlusion, diffusion, and transpiration of gases and liquids, indicate structural, or, as we sometimes term them, molecular differences in mineral species, which make up what we must include under the title of Structural Mineralogy.

§ 32. The changes of mineral species from one condition to another, and their transformations under the influences of the agencies already noticed, including the phenomena of chemism which give rise to new species, make up together the dynamic and chemic activities of matter, which constitute the secular life of the planet. They are the geogenic agencies which, in the course of ages, have moulded the mineral mass of the earth, and from primeval chaos have evolved its present order, formed its various rocks, filled the veins in its crust with metals, ores, gems

* See the author on The Objects and Methods of Mineralogy; Chemical and Geological Essays, p. 453.

and spars, and determined the composition of its waters and its atmosphere. They still regulate alike the terrestrial, the oceanic and the aerial circulation, and preside over the constant change and decay by which the face of the earth is incessantly renewed, and the conditions necessary to organic life are maintained. To the study of these processes we may, with propriety, apply the name of Mineral Physiology.*

* I have elsewhere made use of this term in speaking of the phenomena connected with the decay and transformations of silicated rocks, as belonging to "the domain of what I venture to call mineral physiology." Canadian Naturalist, 1880, new series, vol. ix., page 435.

APPENDIX.

THE doctrine of universal animation, or of an energy inhering in all matter, and that of the essential unity of all manifestations of material energy, whether in dynamic, chemic, or biotic phenomena, both of which we have maintained in the preceding pages, and especially in § 20, were held by Sir Isaac Newton, who ascribed such phenomena to the force of an immanent spirit. In the General Scholium which closes the third volume of the *Principia*, following his magnificent profession of Theism, he asserts the existence of "a most subtile spirit, pervading and latent in all gross bodies," which spirit, by its force and activity, is the cause of gravitation, of cohesion (and consequently of chemism, which he elsewhere refers to peculiar aggregations of particles); of electrical attraction and repulsion; of the phenomena of light and of heat; and finally of all sensation, and of the power of motion in animal bodies.*

* "Adjicere jam liceret nonnulla de spiritu quodam subtillissimo corpora crassa pervadente, et in iisdem latente; cujus vi et actionibus particulæ corporum ad minimes distantias se mutuò attrahunt, et contiguæ factæ cohærunt: et corpora electrica agunt ad distantias majores, tam repellendo quàm attrahendo corpuscula vicina; et lux emittitur, reflectitur, refringitur, inflectitur, et corpore calefacit; et sensatio omnis excitatur̃, et membra animalium ad voluntatem moventur, vibrationibus scilicet hujus spiritus per solida nervorum

capillimenta ab externis sensuum organis ad cerebrum et a cerebro in musculos propagatis." Princip. Math. lib. iii. Scholium Generale·

The same doctrine is enunciated, though in a less precise form, in 1675, in Newton's famous Hypothesis touching his Theory of Light and Color, in his subsequent letter to Boyle in 1679, and also in the Queries 18–24 appended to book III. of his *Optics*, in all of which the various phenomena are ascribed to a supposed ethereal medium. From various considerations it appears probable that these Queries, though first published in 1717, were indited before the *Principia*, which was written in 1685–86, and published in 1687; while the General Scholium itself did not appear till the second edition of the *Principia*, in 1713.

In this connection it may be noticed that the uncertain and obscure utterances found both in Newton's essay of 1675 and in the Queries to the *Optics*, with regard to exhalations from the sun and other celestial bodies, were, after his studies of the comet of 1680, exchanged for the clearly defined opinions in Propositions 41 and 42 of the third book of the *Principia*. In these it is maintained that the exhalations alike from the sun, the fixed stars, and the tails of comets, are not only diffused throughout all space, and finally reach the atmospheres of the planets, but that the matters thus conveyed are necessary for the maintenance of vegetable life, and contribute to the solid mass of our earth. These views were a remarkable anticipation of some of the conclusions announced by the present writer in 1878, and later in 1880, in an essay on The Chemical and Geological Relations of the Atmosphere, for which see the American Journal of Science for May, 1880.

Boston Stereotype Foundry, No. 4 Pearl Street.